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# COMPARISON OF BULLET RESISTANCE OF NEW AND AGED POLY-CARBONATE

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## ABSTRACT

The effects of aging on the ballistic characteristics of monolithic polycarbonate were studied.

The program was carried out in two parts. Part I compared the decrease in bullet velocity after penetration of new to aged polycarbonate panels, and Part II compared the behaviour of new to aged panels where penetration does not occur.

No appreciable difference was noted in residual bullet velocity between those bullets which penetrated the different panels. In assessing bullet resistance through non-penetration, no significant change was observed due to age degradation of the polycarbonate.

It was noted however, that both the artificially aged and naturally aged specimens behaved somewhat unpredictably and both showed signs of being susceptible to the initiation of fractures upon bullet impact.

## 1.0 INTRODUCTION

In the aerospace industry, polycarbonate, either monolithic or laminated, is one of the designers' primary choices when a light-weight high performance transparent material is required. Due to inherent characteristics, transparencies can now withstand the impact of a four pound bird at speeds in excess of 500 knots. Polycarbonate is currently used extensively when designing impact resistant glazings for use in locations susceptible to armed violence such as banks, airports and embassies.

A study carried out at the NRCC/NAE Flight Impact Simulator Facility (Ref. 1) showed a decrease in the bird impact resistance of naturally aged and artificially heat aged polycarbonate. It was on the basis of this work that a joint program to assess the bullet resistance of aged polycarbonate was set up between the Flight Impact Simulator Group and the Public Safety Project Office, NRCC, Ottawa.

The design of the experimental program took account of the fact that double or multiple panels are frequently used in security glazings. When impacted by bullets, the outer panel of the glazing may be penetrated, and in fact a single panel of polycarbonate of ¼ inch thickness can be penetrated by bullets from common types of hand guns. However, the bullet loses energy in the process and may be slowed down to the point where it can be arrested by

the second panel. It therefore seemed important to examine the effect of aging on the behaviour of polycarbonate panels both in the case where impact results in penetration and in the case where it does not. The program was therefore divided into two parts.

Part I was to determine any change in bullet velocity and deviation from line of fire after penetration of single polycarbonate panels. Both artificially and naturally aged material was employed for these tests as well as panels of recently manufactured material for comparative purposes.

Part II was to provide an assessment of the degree of ballistic resistance of the various polycarbonate panels without complete penetration of a two-panel set-up.

In both parts, the effect of multiple impacts was investigated.

## 2.0 TEST APPARATUS

A schematic of the test set-up is shown in Figure 1, and a brief description of each of the components is given in the following sections.

### 2.1 FIREARMS AND SUPPORT

For initial calibration tests a Smith & Wesson Model 19-2, .357 Magnum revolver with a 2.5 inch barrel was used. Ammunition was .38 Special, 158 grain semi-wadcutter + P, manufactured by Winchester-Western.

Part I of the program employed a Dan Wesson Model 15, .357 Magnum revolver which could be fitted with barrels of various lengths. A two inch barrel was used for this part of the program. Ammunition was .357 Magnum, 158 grain semi-wadcutter, manufactured by Winchester-Western. This developed an average bullet velocity at impact of 1063 ft/sec with a corresponding kinetic energy of 397 ft.lb.

Part II was carried out with the same revolver equipped with a six inch barrel and using .38 Special, 158 grain semi-wadcutter, + P ammunition manufactured by Winchester-Western. In this case the average bullet velocity at impact was 987 ft/sec with a corresponding kinetic energy of 337 ft.lb.

The revolver was held in a Ransom Gun Rest which was clamped to a rigid steel frame. Discharge of the firearm was carried out manually by a triggering linkage, integral with the Ransom Rest. Figure 2 shows the set-up.

### 2.2 VELOCITY MEASUREMENT

Two methods were used to measure initial bullet velocity. One utilized a chronograph system manufactured by Oehler Research, incorporating a Model 30 Chronotach, with two Model 55 Photoelectric triggering screens set six feet apart. Redundancy of initial velocity was supplied by an aluminum foil screen system, comprising two screens seven feet apart. A single screen of this system was constructed of two foil sheets separated by a tissue paper insulator. This

assembly was taped to the front of a cardboard panel mounted on a plywood support. D.C. Voltage was applied to the foil sheets, and as a bullet passed through the screen, contact was made between the two sheets. An electrical pulse was thus generated which triggered a timer counter. Bullet velocity was then calculated from the measured time interval between the start and stop screens. Figure 3 shows the light screens and foil screens for initial velocity measurements.

Residual velocity for Part I of the program was determined with a second aluminum foil screen system. The screens set seven feet apart are shown in Figure 4.

## 2.3 PANEL SUPPORT FIXTURE

For Part I, the test panels were set in one of two aluminum fixtures, depending on panel size. The fixtures are shown in Figures 5 and 6.

For Part II the same aluminum fixtures were used, but the two panels were separated by a one inch thick spacer, as shown in Figures 5 and 6. Rubber gaskets were used behind each panel after Test 13, in order to minimize fixture inside edge effects.

The aluminum fixtures were clamped to support structure as shown in Figure 7.

## 2.4 TEST PANELS

For all the tests 0.25 inch thick polycarbonate was used. The overall dimensions of the panels were either 12 inches by 12 inches or 8 inches by 8 inches depending on the amount of material available. Material history is detailed in the following sections.

### 2.4.1 NEW POLYCARBONATE

All the panels were cut from a single sheet and assumed to have an age of less than six months based on information from the supplier.

### 2.4.2 NATURALLY AGED POLYCARBONATE

The naturally aged polycarbonate was obtained from panels that had been used during bird impact tests carried out in 1973, and subsequently stored in a closed cabinet. During storage, the panels could have been subjected to temperature extremes of $40^{o}F$ to $100^{o}F$ and humidity could have ranged from 10% to 100%.

Some material that had been on inventory at a local supplier for approximately two years, and on hand at the facility for another year, was also available.

2.4.3 ARTIFICIALLY HEAT AGED

New as-extruded material was conditioned at 260±5°F for either 100 hours or 196 hours in an air circulating oven. A copper constantan thermocouple connected to a digital indicator and strip chart recorder monitored the temperature during the heat aging. This procedure was previously established and reported in Ref. 1.

## 3.0 METHOD

### 3.1 CALIBRATION

Prior to testing, calibration shots were carried out, measuring bullet velocities with two foil screen systems as located in Figure 1. These were to determine typical bullet velocity loss over the distance between the two systems.

A Smith & Wesson .357 Magnum with a 2.5 inch barrel was used for the calibration shots. Ammunition was .38 Special, 158 grain, semi-wadcutter +P.

### 3.2 GENERAL - PART I and PART II

Before commencing a test series, a cardboard panel was placed on the first light screen, and one at the bullet trap (Fig. 1). Preliminary shots were taken with the firearm mounted in the gun rest, and adjustments made to the gun rest for the desired line of fire. Once this alignment was completed a laser was mounted on a tripod stand in front of the first light screen, (Fig. 8), and adjusted until the beam passed through the center of the bullet holes in the two cardboard panels. The test panel fixture was then positioned so that the laser beam impinged on the desired target point, and the fixture clamped to the support structure (Fig. 7). The aluminum foil velocity screens were also positioned in this manner.

After impact, the laser beam was again positioned to pass through the bullet holes in the foil screens, and the hole in the target panel (Fig. 9). The panel fixture and foil screens were repositioned, for a second impact, using the laser beam as a reference. This procedure was repeated as required.

Impact locations for the first three test shots on a panel were as follows:

- 12 x 12 panels - three equidistant points on the circumference of a six inch diameter circle.

- 8 x 8 panels - three equidistant points on the circumference of a four inch diameter circle.

Impact locations in excess of the initial three were chosen in accordance with panel integrity.

All tests were carried out under ambient room conditions.

A bullet trap (Fig. 10) was positioned down-range.

3.2.1 PART 1

The object of Part I of the program was to compare the residual velocity of a bullet after penetration of new to aged polycarbonate panels. Change in velocity was calculated using the results from the two velocity measuring systems, described in paragraph 2.2.

It was decided at this time to also obtain a measure of bullet deviation from line of fire after penetration. Bullet deviation was obtained by aligning a laser beam through the bullet holes in the initial velocity measuring foil screens, and the hole in the test panel. The panel was then removed, and the point at which the laser beam impinged on the deviation screen at the bullet trap (Fig. 1 and 10) was taken as the true line of fire. The position of the resulting bullet hole on the deviation screen was measured relative to the laser point and the deviation recorded as Y inches vertically up or down, and X inches horizontally left or right.

3.2.2 PART II

The object of Part II was to determine any loss in the bullet resistance of a two-panel polycarbonate set-up due to degradation of the material. The test set-up is shown in Figure 1. Considerable experimentation was required in order to arrive at a combination of handgun calibre, barrel length and ammunition loading which would provide, with new material, bullet penetration of the first panel yet non-penetration of the second.

During testing, the panels were visually checked after each impact and any damage noted and recorded before a subsequent test shot was carried out.

When testing was completed, an attempt was made to ascertain if there was any change in material behaviour of the various panels that actually arrested the bullet. One method considered was to compare the crater depth to the initial bullet velocity. Use of a depth micrometer proved ineffective, due to panel deformation within two inches of the bullet crater.

An alternative method whereby the volume of the crater was compared to the initial velocity of the impacting bullet was then tried. Several unsuccessful methods of measuring the crater volume were attempted before a workable procedure was developed. One unsuccessful procedure was to measure fluid volume with various low viscosity fluids that were dropped into the crater using a hypodermic syringe. Difficulties were encountered due to surface tension effects, static induced capilliary action and indeterminable crater circumferential boundaries. This method was thus discarded.

It was decided that a male casting of the crater could be taken, weighed and converted to volume.

A flat steel washer 7/8 inches ID., when placed on the surface of the panel and centered about the crater, established the circumferential limits of the sample.

Casting material was introduced until the crater was filled and the material overflowed the top surface of the washer. This excess material allowed for any shrinkage experienced during the curing/cooling of the casting. The flat top surface of the washer provided the reference plane to which the casting was trimmed. Silicone rubber and two-part epoxy glue were discarded due to excessive cure times and the possibility of voids. Modeler's clay or Plasticene was not easily released from the crater.

After rejecting several types of material it was found that paraffin wax could be utilized. Molten wax was deposited around the periphery of the washer, centered about the crater, to locate it during the trimming process (Figs. 11 and 12). The crater was then filled to a level above the top surface of the washer. Once the wax had completely solidified the excess was trimmed off flush with the top surface of the washer (Figs. 13 and 14). The panel was inverted and tapped to release the casting (Fig. 15), the washer removed and the wax casting weighed (Fig. 16). This measurement, minus the value for the weight of wax required to fill the hole of the washer, was converted to an equivalent volume. (The density of the paraffin wax was taken to be 0.925 gms/cc.).

## 4.0 RESULTS

### 4.1 CALIBRATION

The results of the calibration shots, measuring the change in bullet velocity over the test set-up distance, are summarized in Table 1. The results showed that the velocity change was insignificant for the purposes of the program and was not considered further.

### 4.2 PART I

The data from Part I are summarized in Table 2. As can be seen from the $\Delta V/V$ results there was no significant change between the different polycarbonate panels of various histories. There was however, some indication that the eight year old naturally aged material was susceptible to fracturing after an initial impact. (See tests 13, 14, 15, 16 and 21). Figures 17 to 20 show the panels from Part I.

Bullet deviation, after penetration, is plotted in Figure 21, and as can be seen from the scatter, seems to be independent of material history.

## 4.3 PART II

The results of Part II are summarized in Table 3, and Figure 22 shows a plot of crater volume versus initial bullet velocity. It should be noted that bullet penetration of panel 2 did not occur in any of the tests. Figure 23 shows typical impact damage in sections taken through panels 1 and 2. The following sections detail the results of the various tests.

### 4.3.1 NEW MATERIAL 12 x 12 PANELS

Results of Tests 4 to 9 inclusive show that the new material can withstand closely spaced (2-5/8 inches apart) multiple impacts without any serious damage to either panel 1 or panel 2.

### 4.3.2 NEW MATERIAL 8 x 8 PANELS

Results of tests 26 to 31 inclusive showed that the outer panel can withstand four impacts approximately 1½ inches apart, but on the fifth, fractures began to initiate from previous damage. Eventually after six impacts the outer panel suffered major damage rendering the set-up non resistant to additional impacts. Figure 24 shows panel 1 after the fifth and sixth impacts. The results from Tests 32 to 35 and Tests 36 to 39 showed fracturing of the outer panel occurring on the third impact with spacing approximately 2-3/4 inches (Figs. 25 and 26). It would be unlikely that an additional impact without bullet penetration of both panels could be carried out.

It is interesting to note that the 12 x 12 panels can withstand at least six impacts without any panel fracturing, while with the 8 x 8 panels, fracturing occurred on the fifth impact in one case and on only the third impact in two cases.

### 4.3.3 NATURALLY AGED (3 YEARS) 12 X 12 PANELS

A total of six impacts (Tests 17 to 22 inclusive) with a minimum spacing of 2¼ inches was carried out on this material without any sign of fractures initiating from existing holes.

### 4.3.4 NATURALLY AGED (8 YEARS) 12 X 12 PANELS

Because of the limited supply of material only one test set-up was assessed.

The first impact, Test 50, caused major damage to panel 2, as shown in Figure 27. Obviously the set-up would not withstand a second impact without bullet penetration of both panels.

#### 4.3.5 NATURALLY AGED (8 YEARS) 8 X 8 PANELS

In tests 23 to 25, with impact spacing similar to that on new material 8 x 8 panels, fracturing occurred in the naturally aged (8 year) material on the second impact, with major damage occurring on the third as shown in Figures 28 and 29. As a result of the damage from the third impact, a fourth would obviously result in bullet penetration of both panels. The aged panels suffered major damage on the third impact compared to the new material, where major damage occurred on the fourth impact in two cases and on the sixth in one case.

#### 4.3.6 ARTIFICIALLY HEAT AGED (100 HOURS) 12 X 12 PANELS

The results of the impacts carried out on these panels were very inconsistent. New material that had been heat aged six months prior to the ballistic tests suffered major damage after just one or two impacts. In Test 3 a large section of panel 2 separated as a result of the single impact. The damage is shown in Figure 30. Fracturing occurred in panel 1 (Test 14, 15 and 16) on the second impact and major damage occurred on the third (Test 16) as shown in Figure 3

Material that was heat aged days prior to testing showed no signs of damage after a total of six impacts with spacing as close as 2½ inches (Tests 40 to 45).

#### 4.3.7 ARTIFICIALLY HEAT AGED (196 HOURS) 12 X 12 PANELS

There were no signs of fracturing of this material after four closely spaced impacts (Tests 46 to 49). Spacing was approximately three inches.

## 5.0 DISCUSSION OF RESULTS

### 5.1 PART I

In the tests carried out on the 12 x 12 panels there was no indication of any difference in either bullet residual velocity or deviation from line of flight after penetration due to material degradation. Fractures occurred in the 8 x 8 panels assessed, on the second impact with the naturally aged material, but as was discovered in Part II, this might be as a result of panel size rather than material degradation.

### 5.2 PART II

#### 5.2.1 PANEL SIZE

Results of multiple impacts carried out on 8 x 8 panels (Tests 26 to 39) showed that with new material fractures initiated from previous damage on the fifth impact in one case and on the third impact in two cases. On the 12 x 12 panels (Tests 4 to 9) no fracturing occurred after six closely spaced impacts. There seems to be a relationship between initiation of fractures and panel size. Because of the velocity of the bullet impact, these results are puzzling and additional testing is suggested.

### 5.2.2 NATURALLY AGED MATERIAL

Tests on three year old material indicated no material degradation.

The single impact on the eight year old material (12 x 12 panels) was quite interesting as the test set-up would not withstand a second impact without penetration of both panels.

Unfortunately, it is difficult to draw any firm conclusion on the basis of a single test, but the result is certainly noteworthy.

Signs of material degradation occurred with the 8 year old 8 x 8 panels (Tests 23, 24 and 25). Fracturing of the outer panel resulted on the second impact, while with the new material 8 x 8 panels the outer panel did not fracture until the third impact in two cases and on the fifth impact in one case.

Obviously more work should be undertaken with naturally aged material, preferably with 12 x 12 panels to minimize possible panel size effects.

### 5.2.3 ARTIFICIALLY AGED MATERIAL

The results from the tests carried out on this material were inconsistent. Material that had been heat aged six months prior to ballistic testing showed degradation as major damage occurred to test panels on only the first or second impact (Tests 14, 15 and 16). However, material that had been heat aged days prior to testing showed no signs of degradation (Tests 40 to 49). This material should be tested at some future date to see if degradation continues after the heat aging process.

### 5.2.4 PLOT OF CRATER VOLUME VRS. INITIAL BULLET VELOCITY

Figure 22 further supports some points discussed in the previous parts. It is quite evident that material behaviour, particularly yielding on impact, had changed as a result of both artificial heat aging, and natural aging. Also, quite evident is the difference in behaviour between the artificially heat aged (100 hours) material that had been processed some six months before testing and the material processed days before.

It is interesting to note that there is a significant difference in crater volume between new material 12 x 12 panels and the 8 x 8 panels, remembering that all the panels were cut from the same sheet. These results again support a panel size effect occurring with the polycarbonate.

A portion of the scatter of the various curves can probably be attributed to the fact that the initial bullet velocity does not relate directly to the velocity of the bullet impacting the second panel. Since the bullet penetrates the first panel the residual impact velocity (relative to initial velocity) can vary somewhat. In addition the shape of the bullet, orientation and deviation also might add to the scatter shown on the curves.

REFERENCES

(1) "Degradation of the Bird Impact Resistance of Polycarbonate" J.B.R. Heath and R.W. Gould, National Research Council of Canada, National Aeronautical Establishment, Laboratory Technical Report LTR-ST-1326, January 1982.

TABLE 1

RESULTS OF CALIBRATION SHOTS
(Average Velocity Change in 10 Feet)

| TEST NO. | INITIAL VEL. ft/sec. | FINAL VEL. ft/sec. | CHANGE IN VEL. ft/sec. |
|---|---|---|---|
| 1 | 833 | 821 | 12 |
| 2 | 815 | 803 | 12 |
| 3 | 807 | 799 | 08 |
| 4 | 817 | 806 | 11 |
| 5 | 805 | 796 | 09 |
| 6 | 814 | 803 | 11 |
| 7 | 777 | 767 | 10 |
| 8 | 821 | 812 | 09 |
| 9 | 826 | 816 | 10 |
| | | | MEAN 10.2 STD. DEV. 1.4 |

## TABLE 2

| TEST No. | PANEL HISTORY | PANEL SIZE (in.) | INITIAL VEL. $V_1$ ft/sec. | FINAL VEL. $V_2$ ft/sec. | $\Delta V = V_1 - V_2$ ft/sec. | $\frac{\Delta V}{V_1}$ | DEFLECTION - Inches U (Up), D (Down) L (Left), R (Right) | RESULTS |
|---|---|---|---|---|---|---|---|---|
| 7 | New | 12 x 12 | 1066 | 781 | 285 | 0.27 | 0.13U, 2.25L. | |
| 8 | Same | Panel | 1071 | 797 | 274 | 0.26 | 0.38U, 1.19L. | |
| 10 | " | " | 1083 | 817 | 266 | 0.25 | 0.13D, 0 | |
| 2 | N - 3* | 12 x 12 | 1112 | 839 | 273 | 0.25 | 0.75D, 0.19R. | |
| 3 | Same | Panel | 1043 | 735 | 308 | 0.30 | 0.75D, 1.13R. | |
| 5 | " | " | 1033 | 733 | 300 | 0.29 | 1.13U, 0.75L. | |
| 13 | N - 8 | 8 x 8 | 1002 | 688 | 314 | 0.31 | 0.5U, 1.88L. | |
| 14 | Same | Panel | 1116 | 654 | 262 | 0.24 | 0.69D, 0.19L. | Fracture from panel edge to hole test 13 almost to hole test 14 |
| 15 | N - 8 | 8 x 8 | 1044 | 764 | 280 | 0.27 | [illegible].13D, 1.13R. | Fracture from test 15 hole. Fracture through all holes. |
| 16 | Same | Panel | 1069 | 791 | 278 | 0.26 | 1.13D, 1.88L. | |
| 21 | " | " | 1081 | 796 | 285 | 0.26 | 0.69D, 2.38L. | |
| 11 | A.A.** | 12 x 12 | 1056 | 751 | 305 | 0.29 | 1.19U, 1.88L. | |
| 19 | Same | Panel | 1082 | 773 | 309 | 0.29 | 1.69U, 1.88L. | |
| 20 | " | " | 1021 | 695 | 326 | 0.32 | 2.0D. Z.44R. | |

* Naturally Aged - X years

** Artificially Heat Aged - 100 hrs.

TABLE 3

| TEST | PANEL HISTORY | PANEL SIZE (in.) | INITIAL VEL. ft/sec. | PANEL 1 | PANEL 2 | VOLUME of CRATER PANEL 2 (cc) | COMMENTS |
|---|---|---|---|---|---|---|---|
| 4 | New | 12 x 12 | 1000 | Pen | No Pen | .380 | All shots within 6 in., dia., circle shots 4 and 9 spaced 2-5/8 apart. No signs of fracturing. |
| 5 | Same | Panel | 976 | " | " | .320 | |
| 6 | " | " | 993 | " | " | .376 | |
| 7 | " | " | 1004 | " | " | .383 | |
| 8 | " | " | 997 | " | " | .339 | |
| 9 | " | " | 962 | " | " | .275 | |
| 26 | New | 8 x 8 | 981 | Pen | No Pen | .267 | All shots within 4 in., dia., circle. |
| 27 | Same | Panel | 1003 | " | " | .274 | |
| 28 | " | " | 995 | " | " | .306 | |
| 29 | " | " | 968 | " | " | .190 | |
| 30 | " | " | 991 | " | " | | Crack from test 26 to bottom L.H. corner crack from test 27 intersecting 1st crack - Test 31 at intersection of cracks, piece broke out of $P_1$ resulting in 1 in., dia., hole. |
| 31 | " | " | 980 | " | " | | |

Table 3 cont.

TABLE 3

*cont. (a)*

| TEST No. | PANEL HISTORY | PANEL SIZE (in.) | INITIAL VEL. ft/sec. | PANEL 1 | PANEL 2 | VOLUME of CRATER PANEL 2 (in.) | COMMENTS |
|---|---|---|---|---|---|---|---|
| 32 | New | 8 x 8 | 986 | Pen | No Pen | .299 | All shots within 4 inch dia., |
| 33 | Same | Panel | 991 | " | " | .290 | circle. Crack from Test |
| 34 | " | " | 989 | " | " | | 32, 1½ in., crack from 33 |
| 35 | " | " | 991 | " | " | | 4 in. Extensive Panel 1 damage. |
| 36 | New | 8 x 8 | 982 | Pen | No Pen | .283 | All shots within 4 in. dia. |
| 37 | Same | Panel | 1000 | " | " | .374 | circle. Crack from test |
| 38 | " | " | 973 | " | " | | 36, 1¼ in. Extensive |
| 39 | " | " | 971 | " | " | | Panel 1 damage. |
| 17 | N - 3* | 12 x 12 | 1001 | " | " | .243 | All shots within 6 in. dia. |
| 18 | Same | Panel | 995 | " | " | .235 | circle. |
| 19 | " | " | 998 | " | " | .277 | |
| 20 | " | " | 1016 | " | " | .330 | |
| 21 | " | " | 1000 | " | " | .248 | |
| 22 | " | " | 931 | " | " | .201 | No panel fracturing |

TABLE 3 co.t. (b)

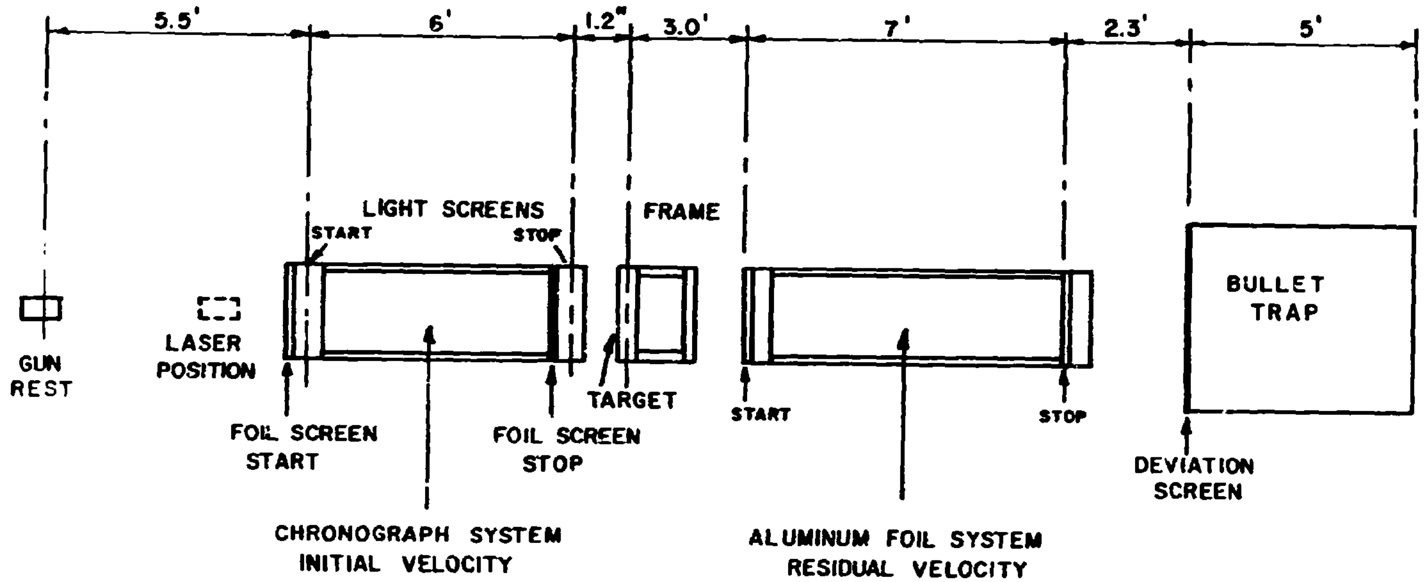
| TEST No. | PANEL HISTORY | PANEL SIZE (in.) | INITIAL VEL. ft/sec. | PANEL 1 | PANEL 2 | VOLUME of CRATER PANEL 2 (in.) | COMMENTS |
|---|---|---|---|---|---|---|---|
| 23 | N - 8 | 8 x 8 | 974 | Pen | No Pen | .209 | All shots within 4 in. dia. cracking from test 23 large piece (7 x 3) separated from panel 1. |
| 24 | Same | Panel | 1001 | " | " | | |
| 25 | " | " | 974 | " | " | | |
| 50 | N - 8 | 12 x 12 | 973 | Pen | Pen | | Large piece (4 in. dia.) separated from panel 2 major cracking occurred. |
| 03 | AA, 100 hrs. + 6 mos. | 12 x 12 | 972 | Pen | Pen | | Major cracking in panel 2 large piece (3 x 4 x 5) separated from panel. |
| 10 | AA, 100 hrs. + 6 mos. | 12 x 12 | 989 | Pen | No Pen | .204 | All shots within 6 in. dia. |
| 11 | Same | Panel | 993 | " | " | .207 | |
| 12 | " | " | 999 | " | " | .207 | Cracking along edge of panel 2, - 6 in. long. Continuation of cracking due to edge of support frame. |
| 13 | " | " | 995 | " | " | | |

TABLE 3

cont. (c)

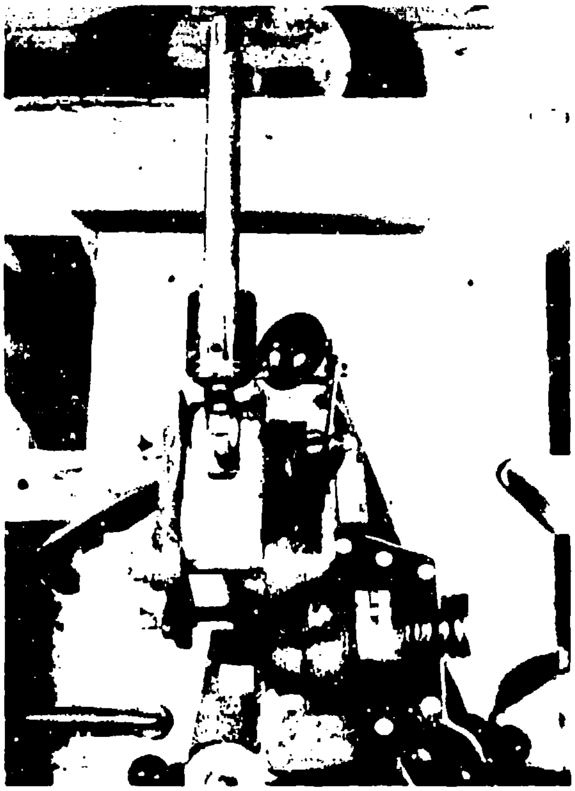
| TEST No. | PANEL HISTORY | PANEL SIZE (in.) | INITIAL VEL. ft/sec. | PANEL 1 | PANEL 2 | VOLUME of CRATER PANEL 2 (in.) | COMMENTS |
|---|---|---|---|---|---|---|---|
| 14 | AA, 100 hrs + 6 mos. | 12 x 12 | 10C0 | Pen | No Pen | .189 | All shots within 6 in. , dia., major crack along top edge major damage to panel 1, large piece 5 x 1½ separated from top cor. |
| 15 | Same | Panel | 996 | " | " | | |
| 16 | " | " | 994 | " | " | | |
| 40 | AA, 100 hrs | 12 x 12 | 992 | Pen | No Pen | .294 | All shots within 6 in. dia. |
| 41 | Same | Panel | 999 | " | " | .326 | |
| 42 | " | " | 968 | " | " | .195 | |
| 43 | " | " | 973 | " | " | .246 | |
| 44 | " | " | 949 | " | " | .128 | |
| 45 | " | " | 949 | " | " | .126 | |
| 46 | AA 196 hrs | 12 x 12 | 961 | Pen | No Pen | .156 | All shots within 6 in. dia |
| 47 | Same | Panel | 982 | " | " | .186 | |
| 48 | " | " | 1013 | " | " | .350 | |
| 49 | " | " | 1000 | " | " | .265 | |

* Naturally aged 3 years.
** Artificially heat aged.

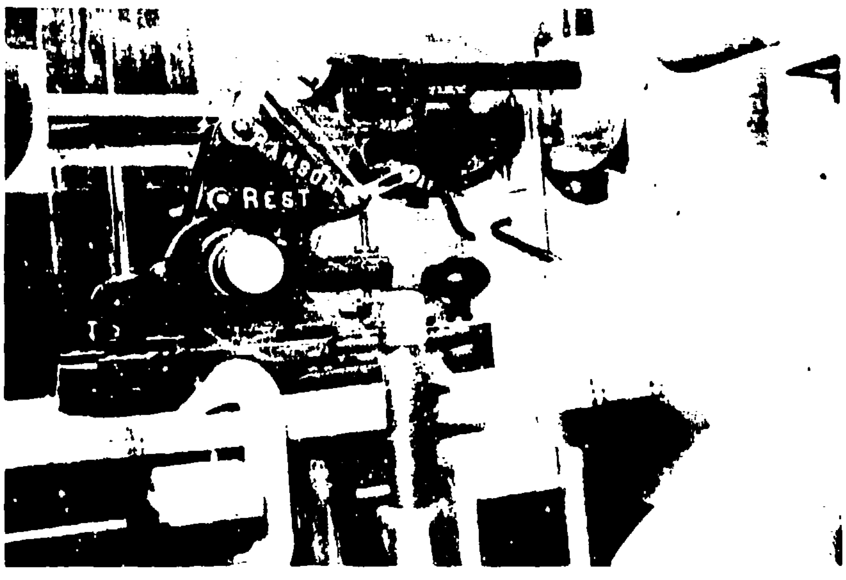



* CALIBRATION - NO TARGET
PART I - AS ABOVE
PART II - RESIDUAL VELOCITY SYSTEM REMOVED

FIG. 1 SCHEMATIC OF SET-UP *



TOP VIEW




SIDE VIEW

FIG. 2 GUN REST SET-UP

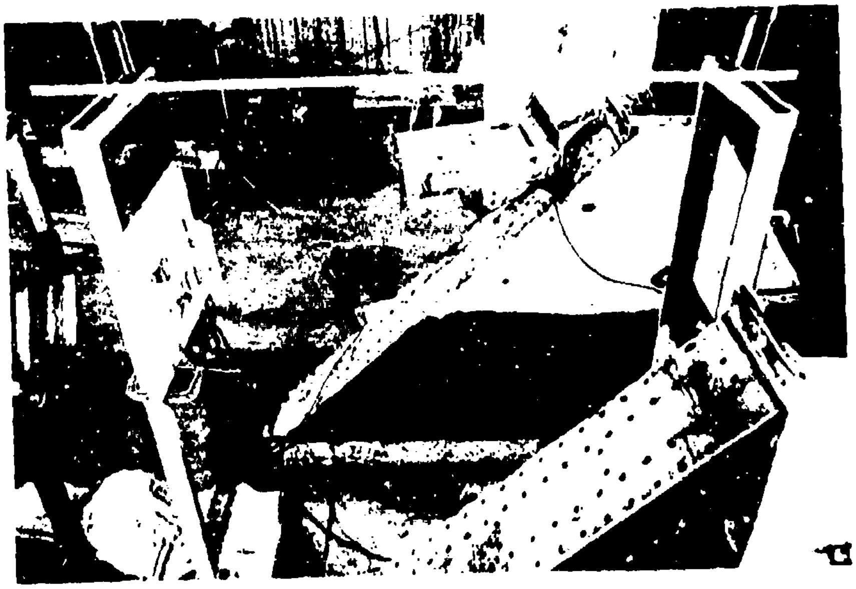
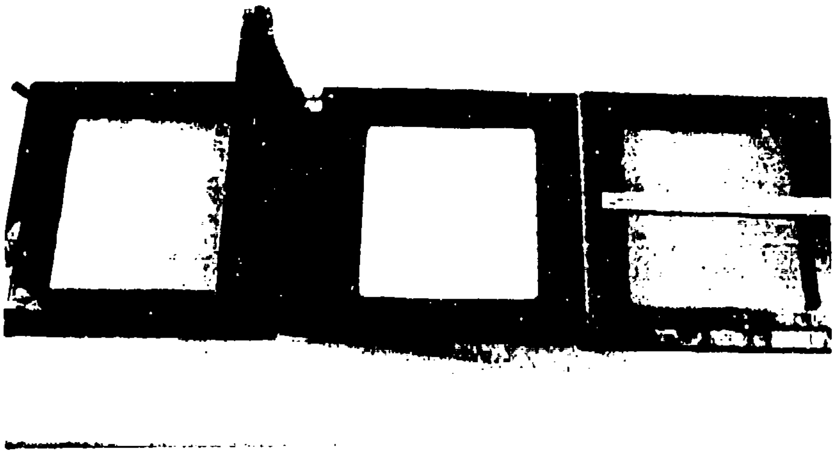
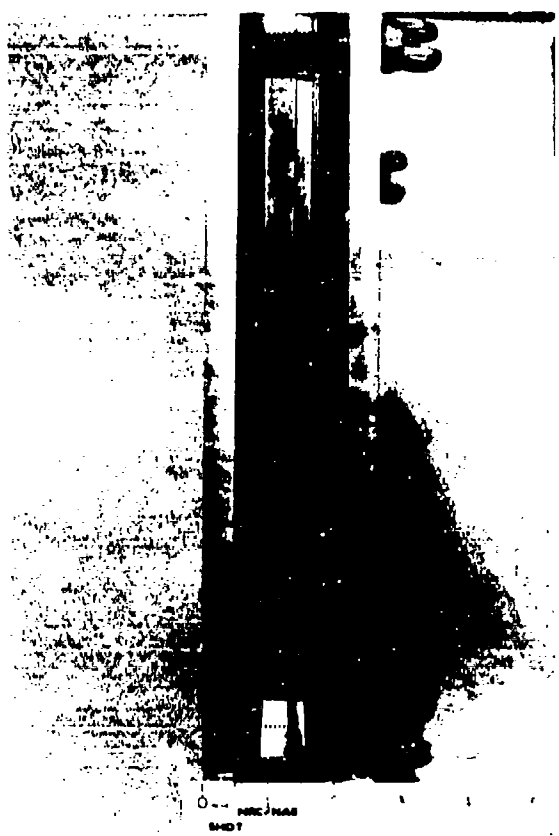


FIG. 3 FOIL SCREENS MOUNTED ON LIGHT SCREEN FRAMES - INITIAL VELOCITY MEASUREMENT

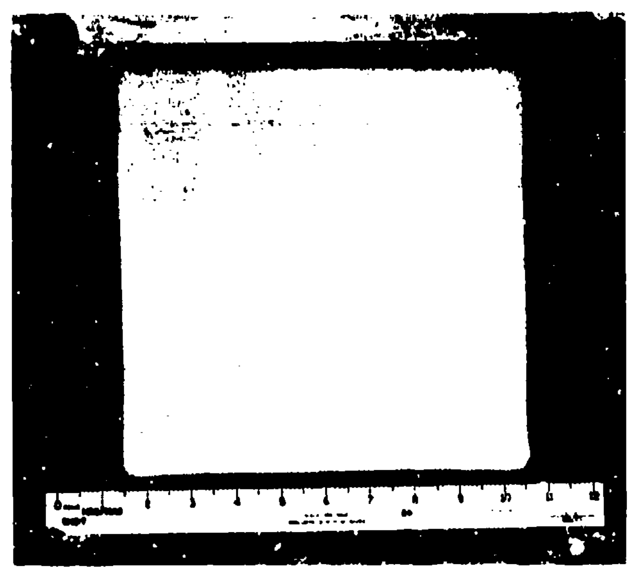
FIG. 4 FOIL SCREENS ON 7FT. FRAME - RESIDUAL VELOCITY MEASUREMENT



(a) COMPONENTS

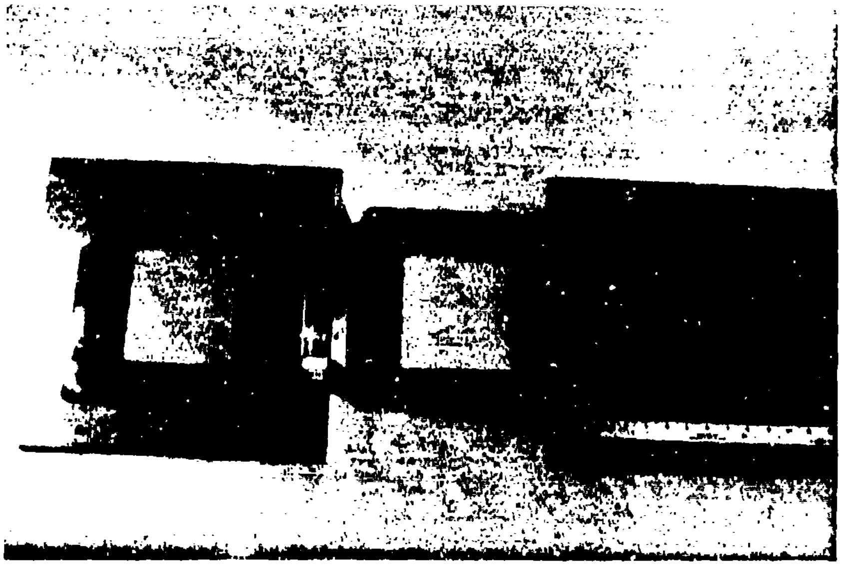


(b) SIDE VIEW
(PART II SET-UP)



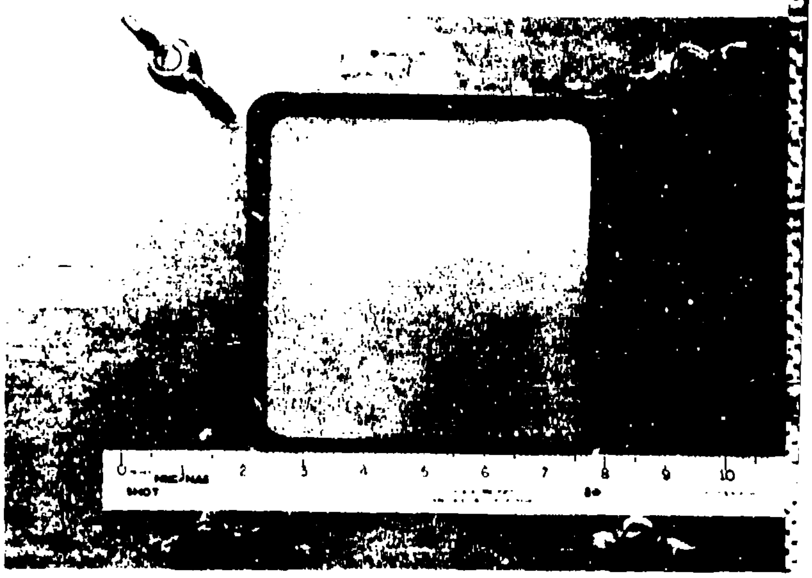
(c) FRONT VIEW

FIG. 5 TEST FIXTURE - 12" × 12" PANEL



(a) COMPONENTS

(b) SIDE VIEW
(PART II SET-UP)



(c) FRONT VIEW

FIG. 6 TEST FIXTURE - 8" x 8" PANEL

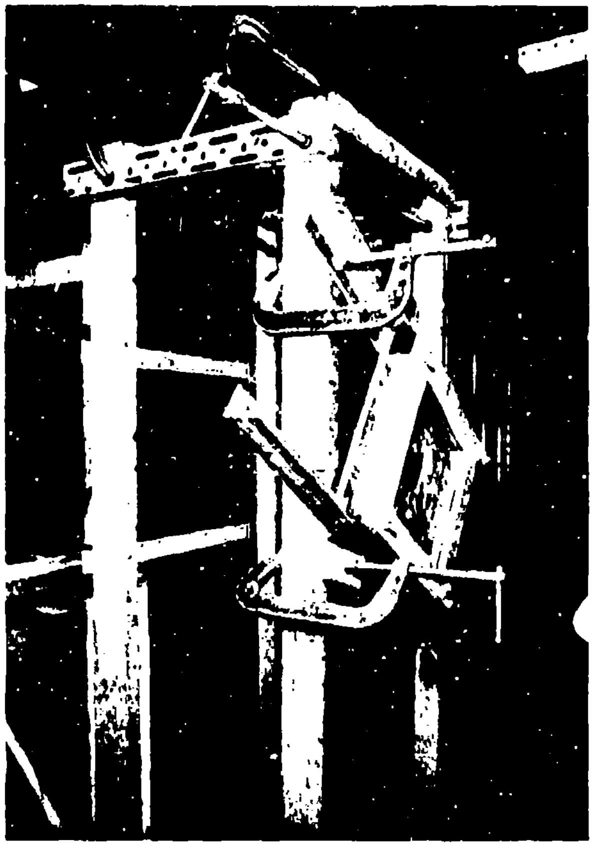
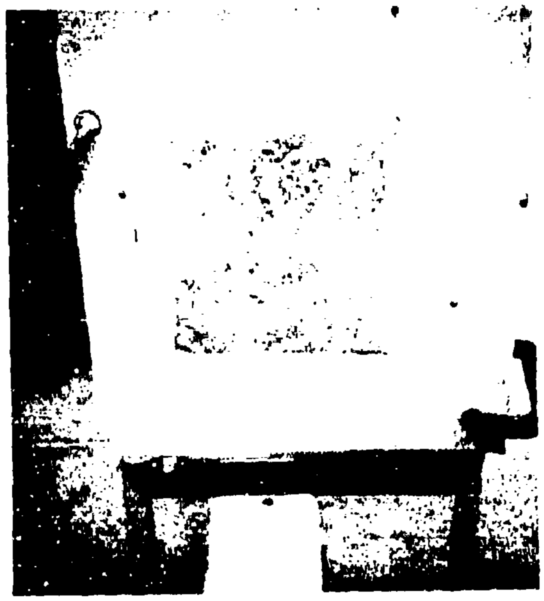
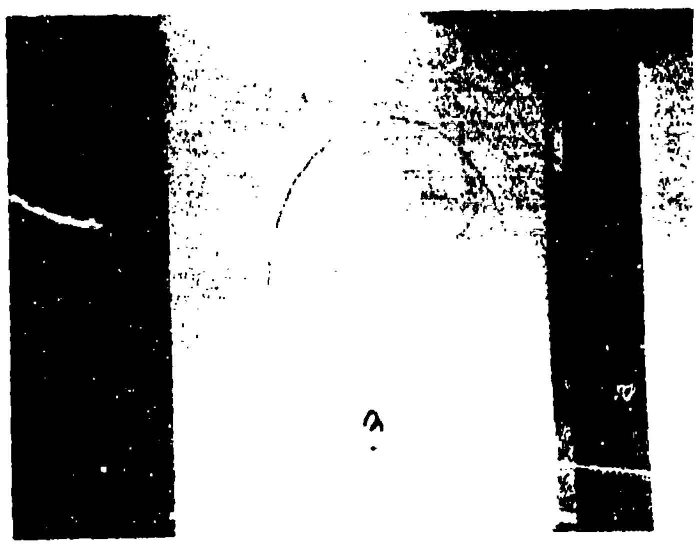


FIG. 7 TEST FIXTURE CLAMPED TO SUPPORT STRUCTURE

FIG. 8 LASER MOUNTED ON TRIPOD



(a) LASER BEAM PROJECTED THROUGH BULLET HOLES IN INITIAL VELOCITY SCREENS



(b) LASER BEAM PROJECTED THROUGH BULLET HOLE IN TEST PANEL

FIG. 9 ALIGNMENT OF SCREENS AND TEST FIXTURE

FIG. 10 BULLET TRAP

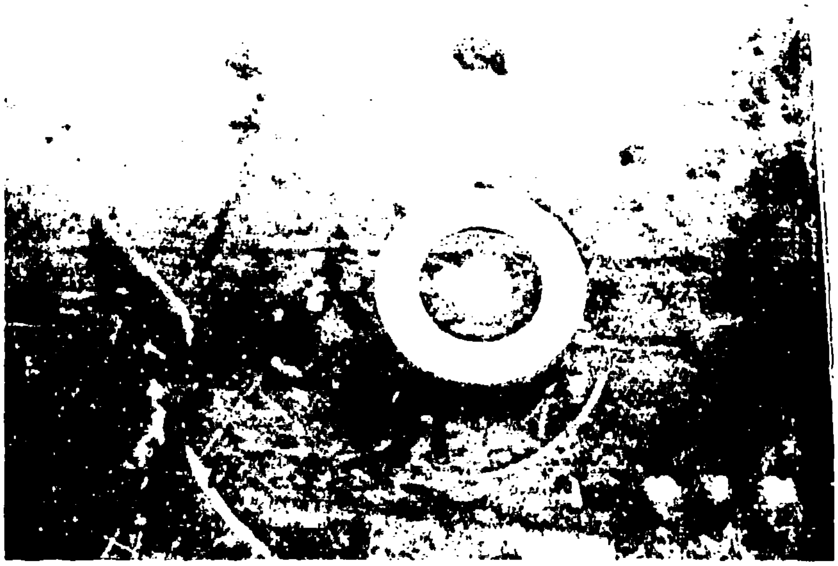


FIG. 11 FLAT STEEL WASHER CENTERED ABOUT CRATER

FIG. 12 PARAFFIN WAX DEPOSITED INTO CRATER AND TO LOCATE WASHER

FIG. 13 PARAFFIN WAX TRIMMED FLUSH

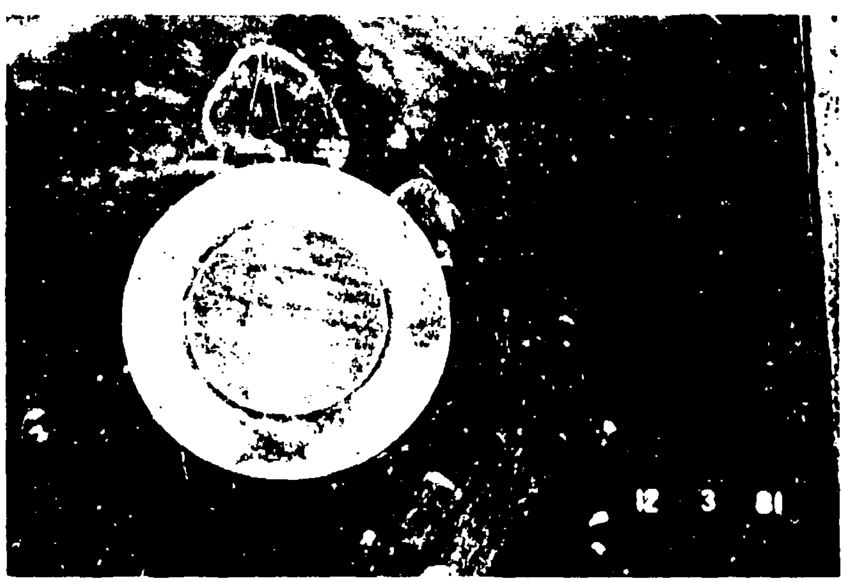


FIG. 14 WAX LOCATING DEPOSITS REMOVED

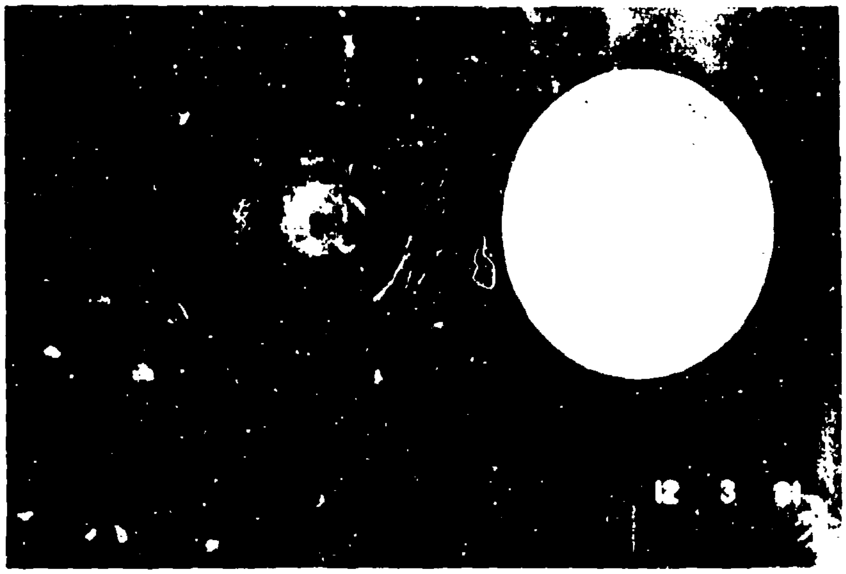


FIG. 15 WAX CASTING REMOVED

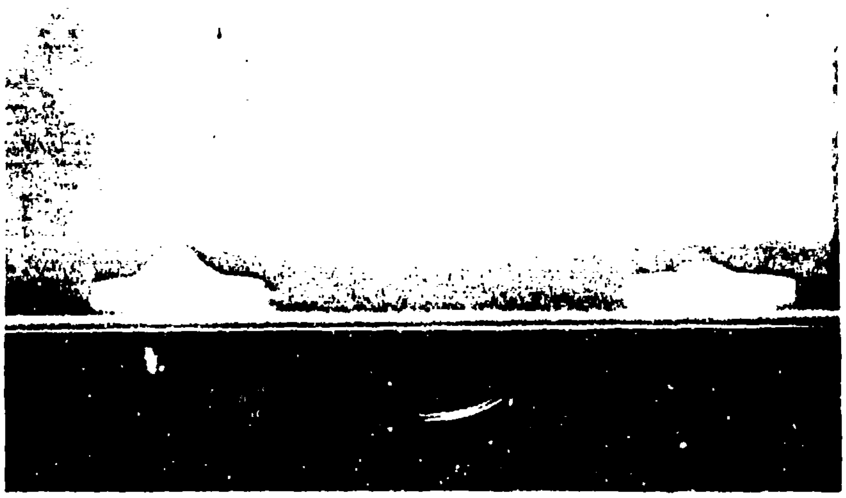


FIG. 16 EXAMPLES OF WAX CASTINGS, STEEL WASHER REMOVED, READY FOR WEIGHING

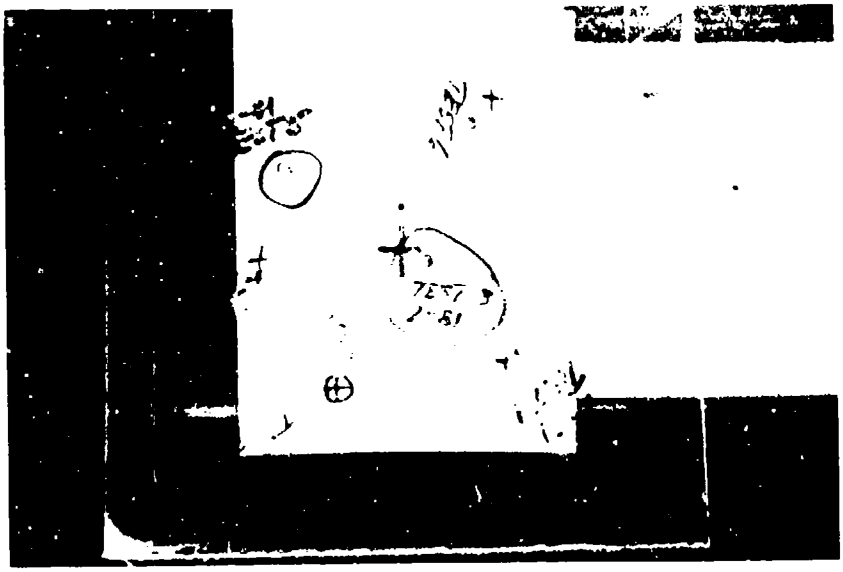


FIG. 17 TESTS 1 TO 6
PART I

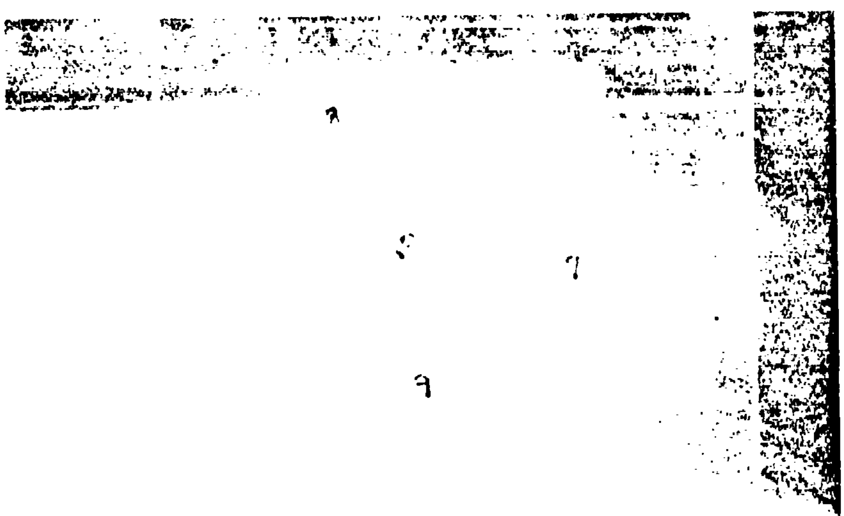


FIG. 18 TESTS 7 TO 10
PART I

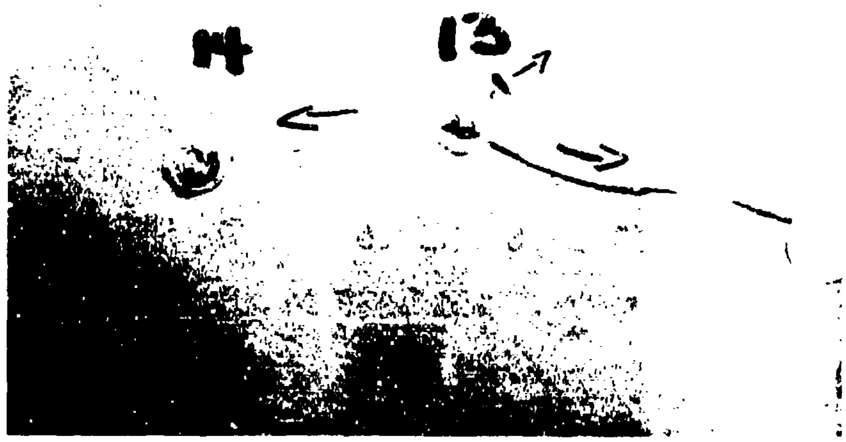
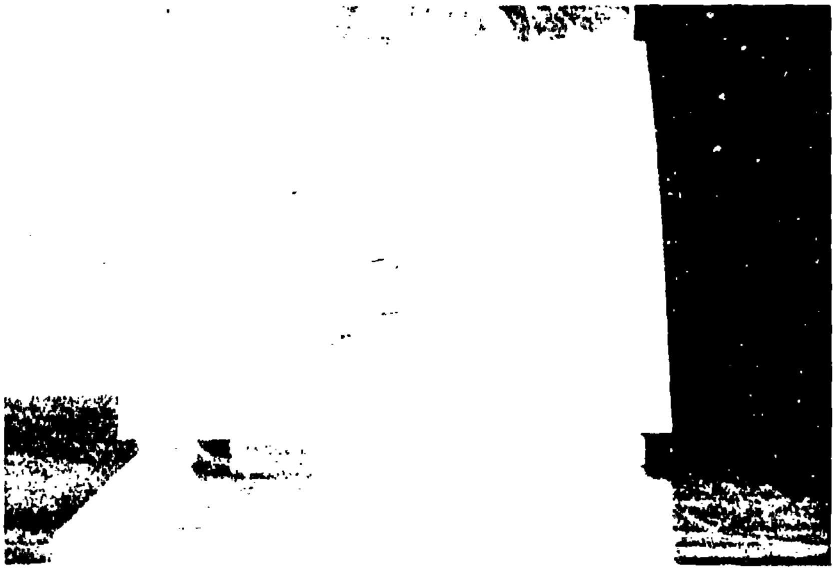
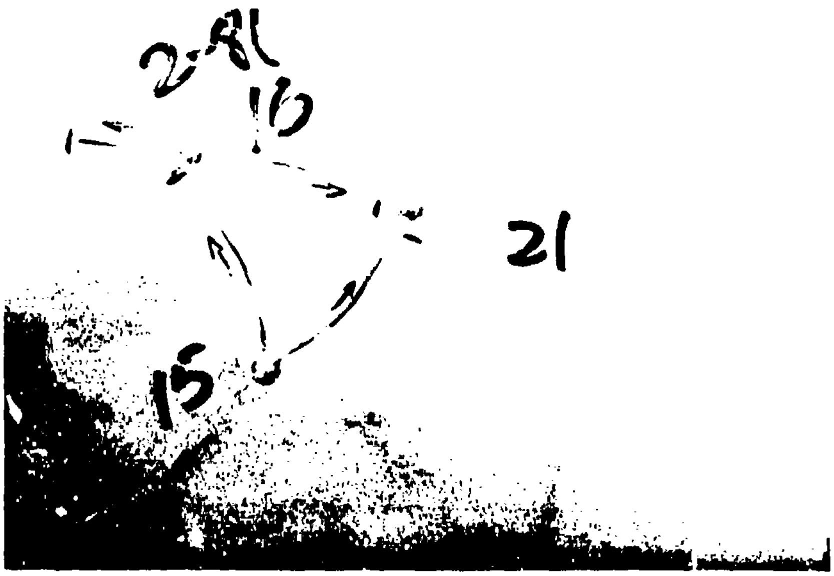



FIG. 19 TESTS 13 AND 14
PART I



(a) TESTS 15 AND 16




(b) TESTS 15, 16 AND 21

FIG. 20 PART I

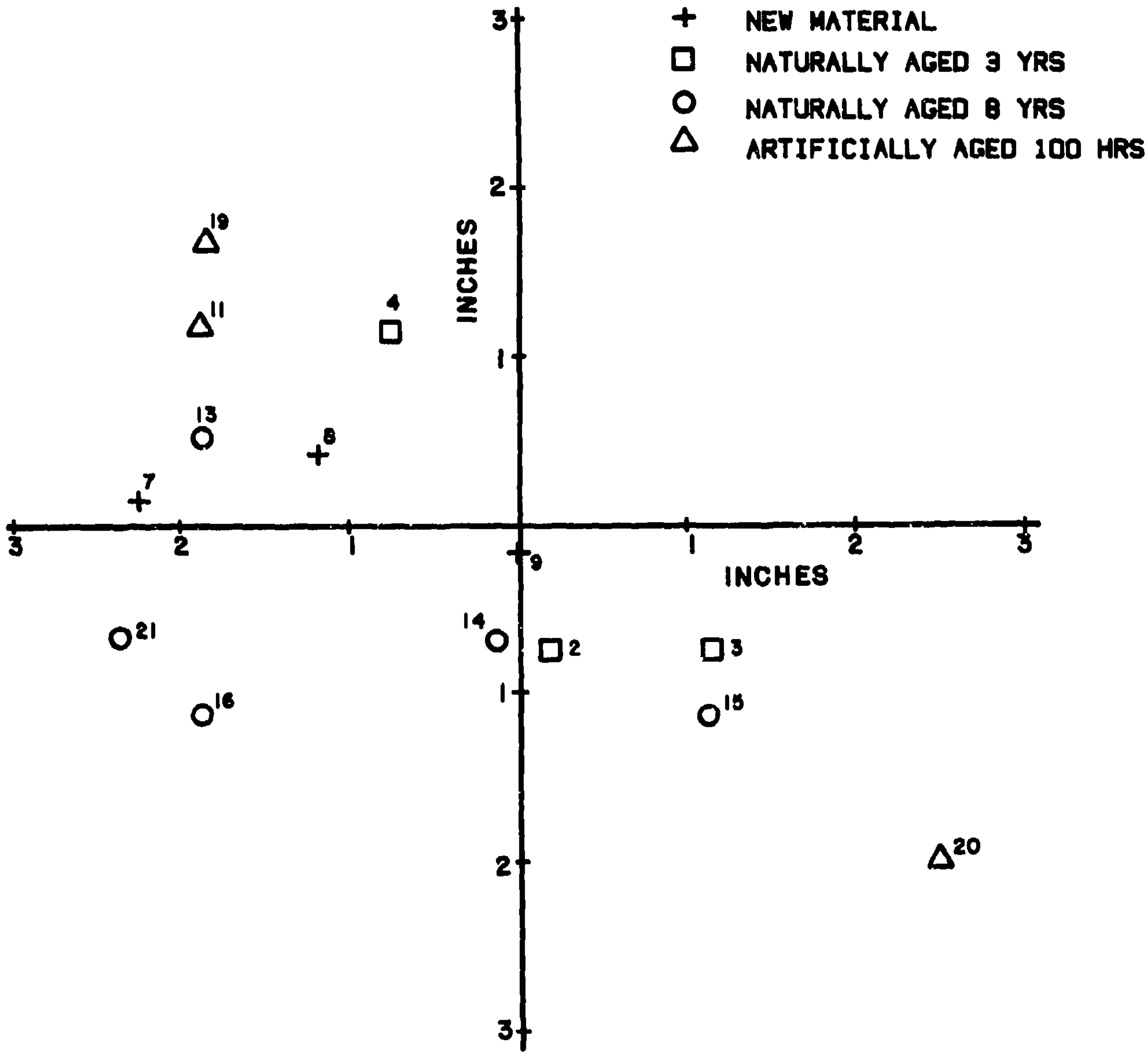
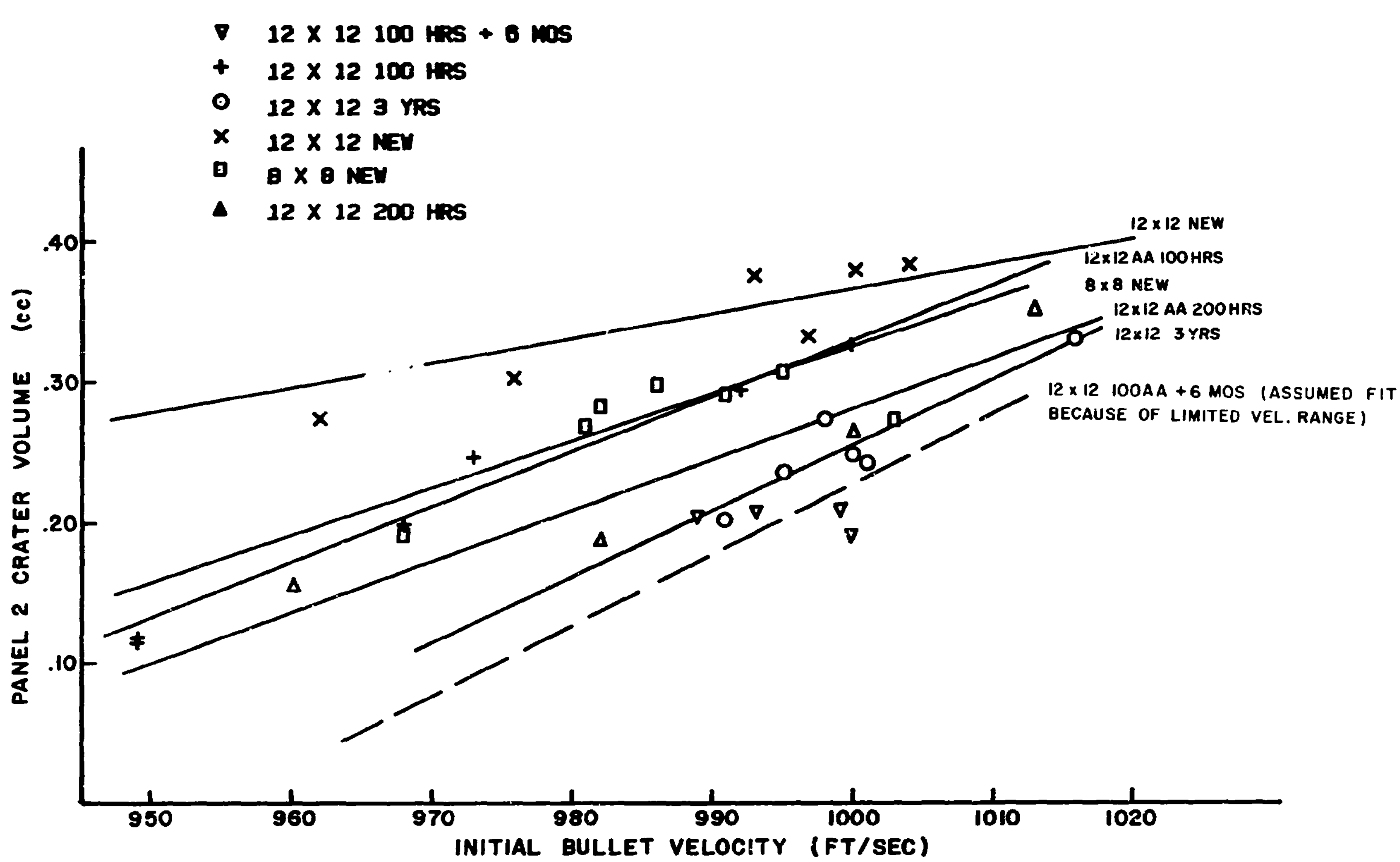



FIG. 21 BULLET POSITIONS ON DEVIATION SCREEN AFTER PANEL PENETRATION

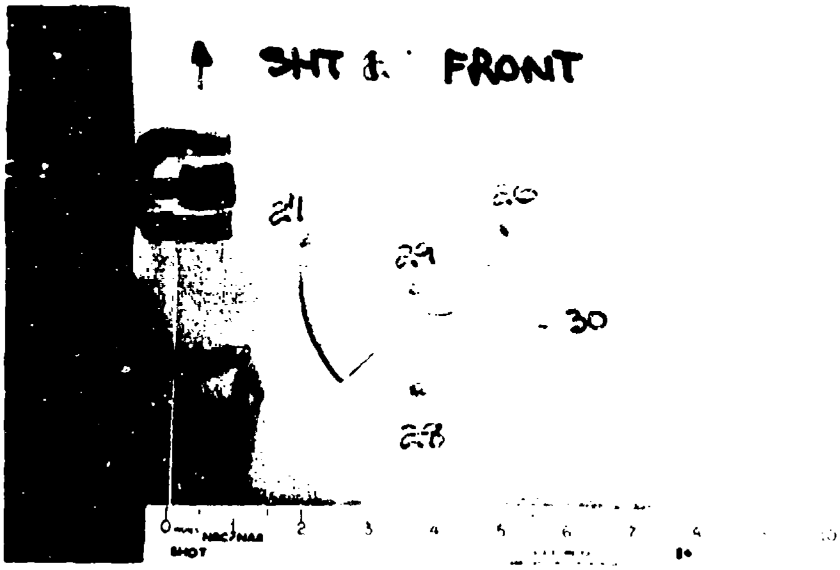


▼ 12 X 12 100 HRS + 6 MOS
+ 12 X 12 100 HRS
o 12 X 12 3 YRS
× 12 X 12 NEW
□ 8 X 8 NEW
▲ 12 X 12 200 HRS
12 x 12 NEW
12x12 AA 100HRS
8 x 8 NEW
12x12 AA 200HRS
12x12 3 YRS
12 x 12 100AA + 6 MOS (ASSUMED FIT BECAUSE OF LIMITED VEL. RANGE)
PANEL 2 CRATER VOLUME (cc)
.40
.30
.20
.10
950
960
970
980
990
1000
1010
1020
INITIAL BULLET VELOCITY (FT/SEC)

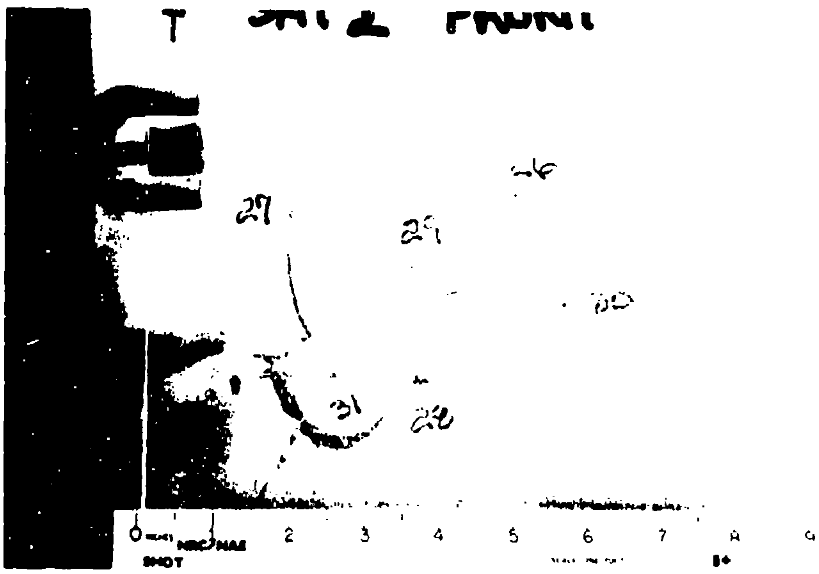

FIG. 22

P1 P2

FIG. 23 TYPICAL IMPACT DAMAGE - PART II

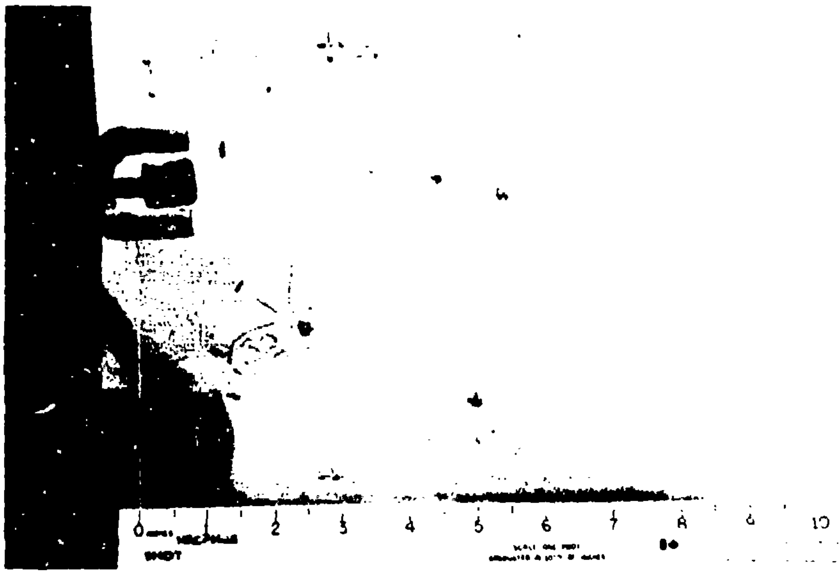



(a) DAMAGE AS A RESULT OF TEST 30




(b) DAMAGE AS A RESULT OF TEST 31

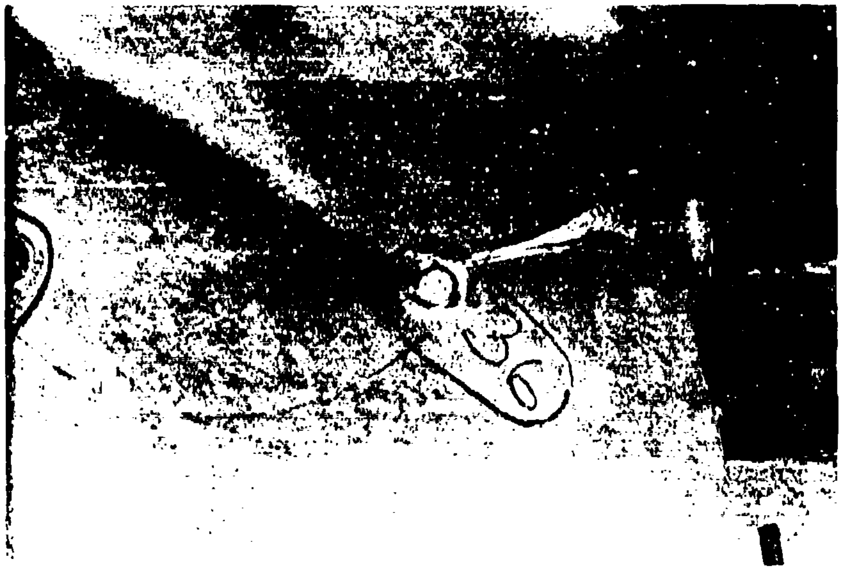
FIG. 24 TESTS 26 TO 31 - PANEL P1 - PART II



(a) DAMAGE AS A RESULT OF TEST 34

(b) DAMAGE AS A RESULT OF TEST 35

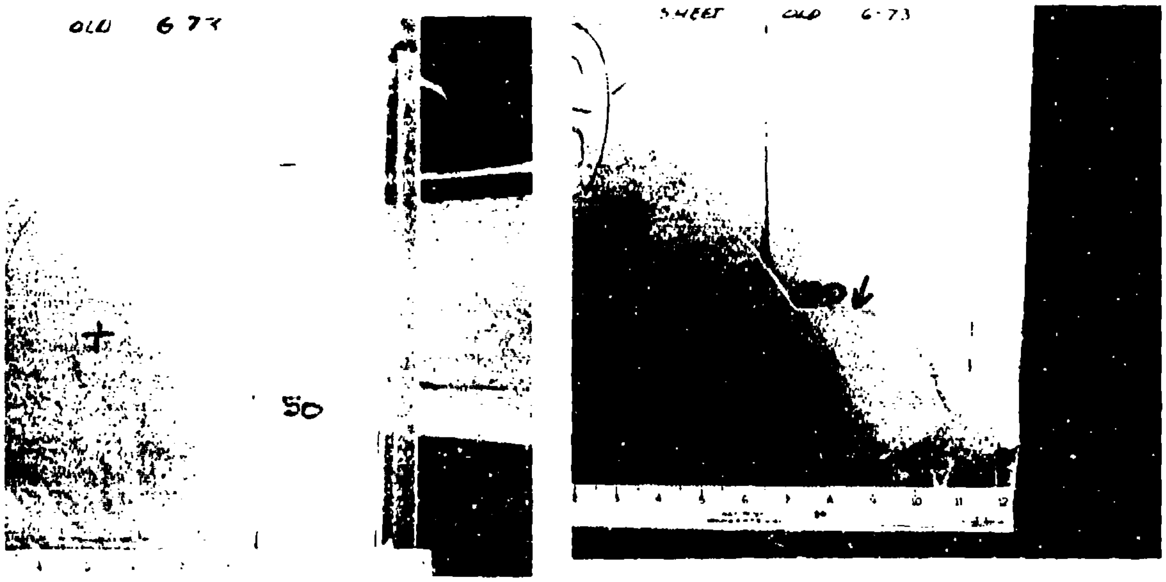
FIG. 25 TESTS 32 TO 35 - PANEL P1 - PART II



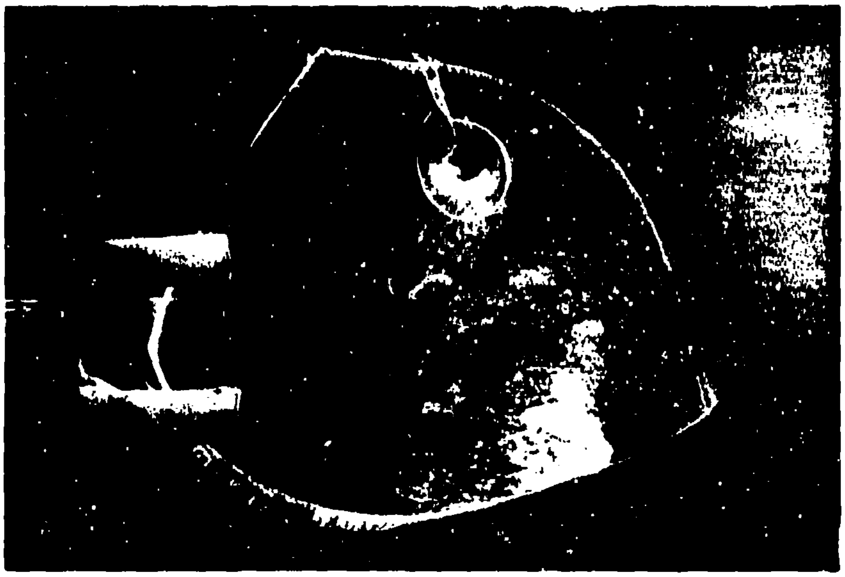

(a) DAMAGE AS A RESULT OF TEST 38


(b) DAMAGE AS A RESULT OF TEST 39

FIG. 26 TESTS 36 TO 39 - PANEL P1 - PART II

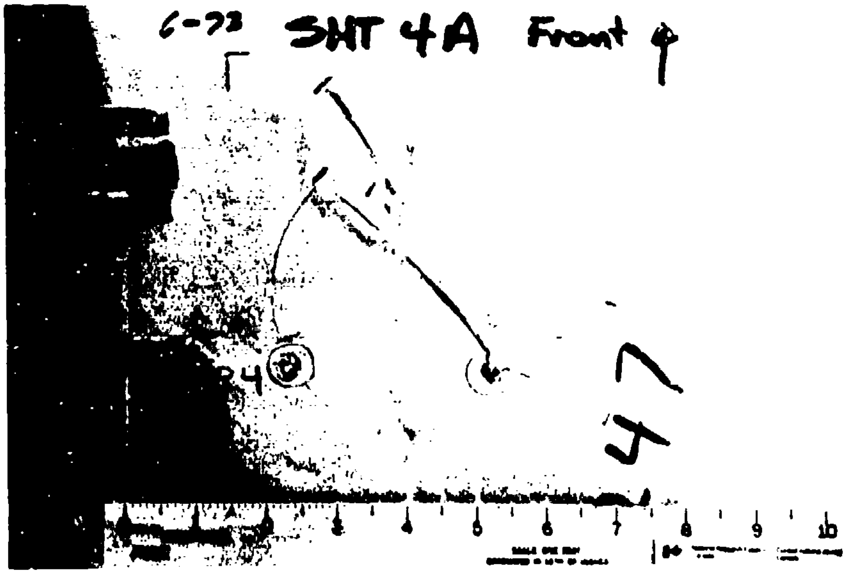



(a) P1 P2

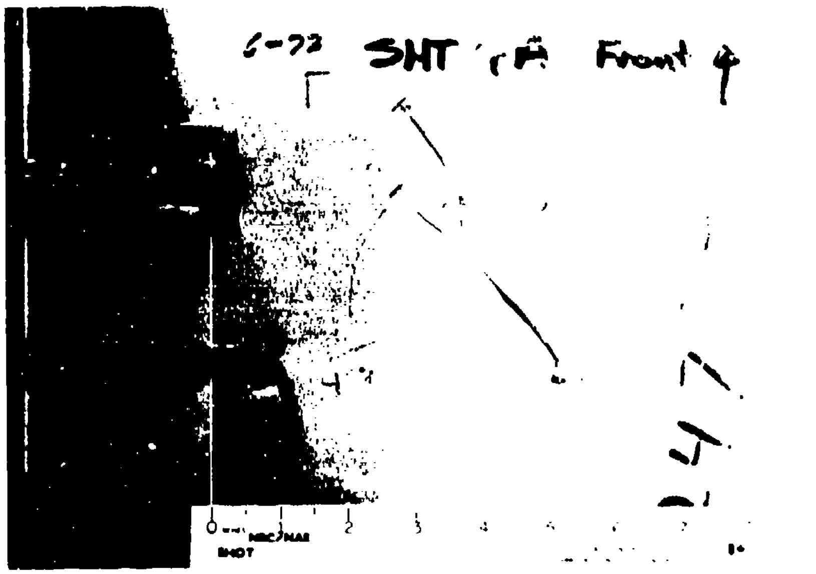


(b) PIECE SEPARATED FROM P2

FIG. 27 TEST 50 - PART II




(a) DAMAGE AS A RESULT OF TEST 24




(b) DAMAGE AS A RESULT OF TEST 25

FIG. 28 TESTS 23 TO 25 - PANEL P1 - PART II

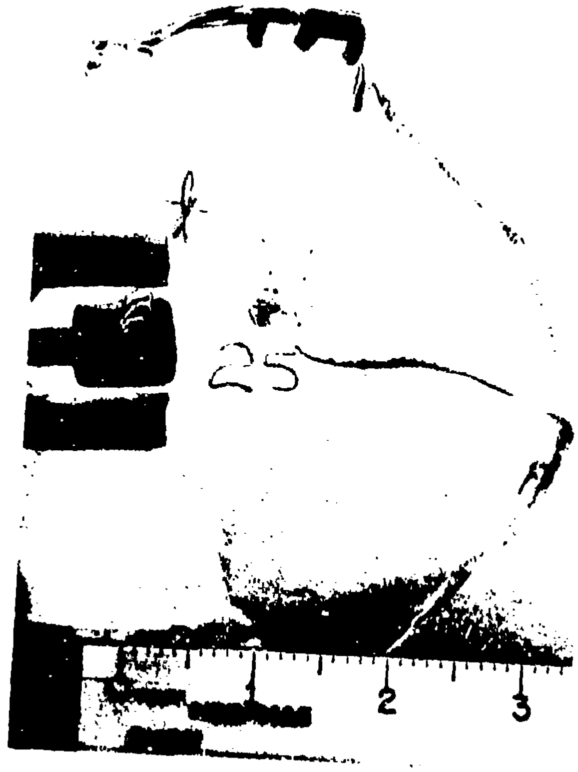
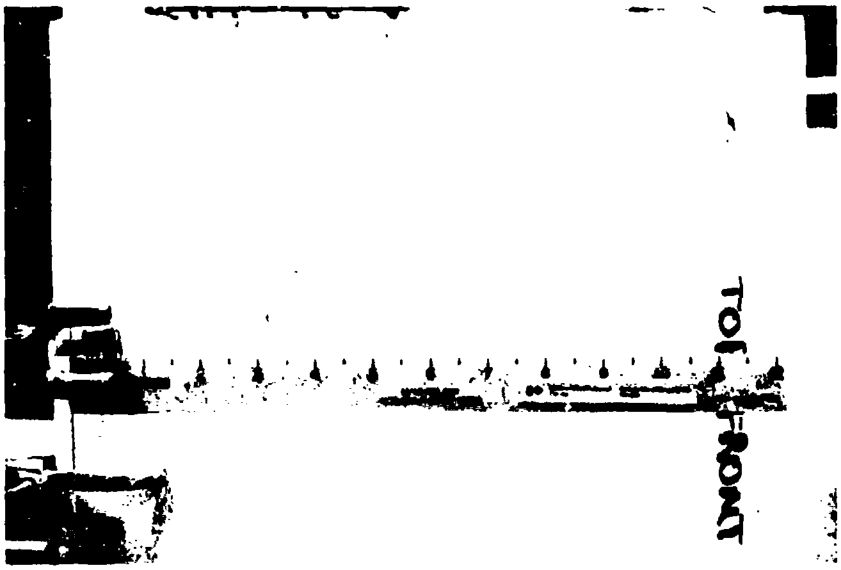
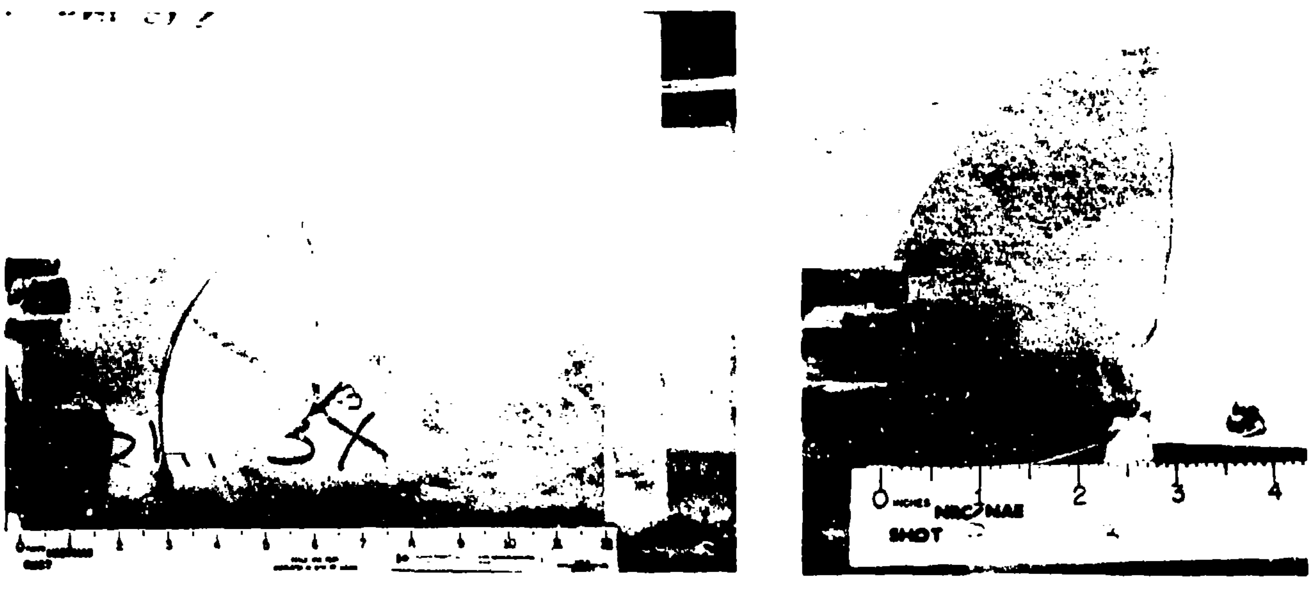



FIG. 29 PIECE SEPARATED FROM P1
TEST 25 - PART II

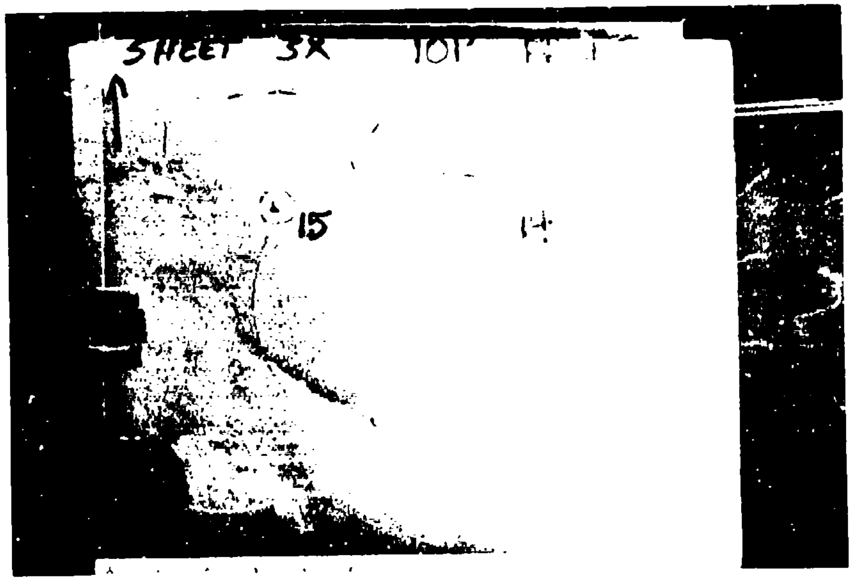



(a) PANEL P1

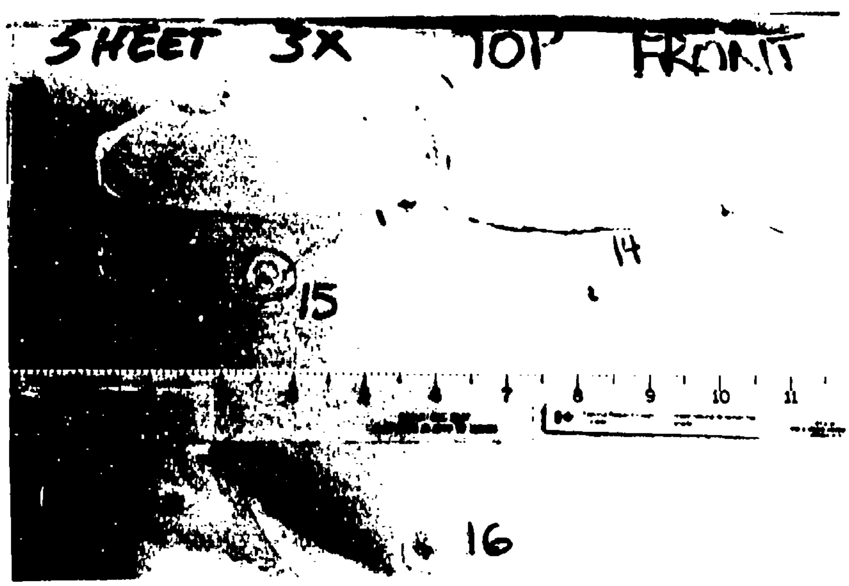



(b) DAMAGE, PANEL P2

FIG. 30 TEST 3 - PART II




(a) DAMAGE AS A RESULT OF TEST 15




(b) DAMAGE AS A RESULT OF TEST 16

FIG. 31 TESTS 14 TO 16 - PANEL P1 - PART II